Active

Project #: E-21-674　　Cost share #: E-21-348　　Rev #: 5
Center # : 10/24-6-R7145-0A0　　Center shr #: 10/22-1-F7145-0A0　　OCA file #:
Work type : RES
Contract#: N00014-91-J-1334　　Mod #: A00002　　Document : GRANT
Prime #:　　Contract entity: GTRC

Subprojects ? : Y　　CFDA: 12.AAA
Main project #:　　PE #: N/A

Project unit: ECE　　Unit code: 02.010.118
Project director(s):
ZABIN S M　　ECE　　(404)853-9494

Sponsor/division names: NAVY / OFC OF NAVAL RESEARCH
Sponsor/division codes: 103 / 025

Award period: 910125 to 940331 (performance) 940331 (reports)

Sponsor amount	New this change	Total to date
Contract value	0.00	193,000.00
Funded	0.00	193,000.00
Cost sharing amount		43,886.00

Does subcontracting plan apply ?: N

Title: SIGNAL PROCESSING IN IMPULSIVE ELECTROMAGNETIC INTERFERENCE

PROJECT ADMINISTRATION DATA

OCA contact: E. Faith Gleason　　894-4820

Sponsor technical contact	Sponsor issuing office
RABINDER N. MADAN	DOUG HEATON
(703)696-4217	(404)730-9257
OFFICE OF CHIEF OF NAVAL RESEARCH	ONR RR
800 N. QUNICY STREET	101 MARIETTA TOWER, SUITE 2805
ARLINGTON, VA 22217-5000	101 MARIETTA STREET
	ATLANTA, GA 30323

Security class (U,C,S,TS) : U　　ONR resident rep. is ACO (Y/N): Y
Defense priority rating : NA　　ONR supplemental sheet
Equipment title vests with: Sponsor　　GIT X

Administrative comments -
MOD NO. A00002 PROVIDES A 3-MONTH NO-COST EXTENSION TO MARCH 31, 1994, IN ACCORDANCE WITH OCA LETTER DATED DECEMBER 20, 1993.

SK 254 2

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 09/01/95

Project No. E-21-674 Center No. 10/24-6-R7145-0A0

Project Director ZABIN S M School/Lab ECE

Sponsor NAVY/OFC OF NAVAL RESEARCH

Contract/Grant No. N00014-91-J-1334 Contract Entity GTRC

Prime Contract No.

Title SIGNAL PROCESSING IN IMPULSIVE ELECTROMAGNETIC INTERFERENCE

Effective Completion Date 940331 (Performance) 940331 (Reports)

Closeout Actions Required:		Date Submitted
Final Invoice or Copy of Final Invoice	Y	
Final Report of Inventions and/or Subcontracts	Y	
Government Property Inventory & Related Certificate	N	
Classified Material Certificate	N	
Release and Assignment	N	
Other	N	

Comments

Subproject Under Main Project No.

Continues Project No.

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	N
Reports Coordinator (OCA)	Y
GTRC	Y
Project File	Y
Other	N
	N

NOTE: Final Patent Questionnaire sent to PDPI.

E21-614

#7

GEORGIA INSTITUTE OF TECHNOLOGY
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June 18, 1991

Dr. Rabinder N. Madan
Program Manager
Systems and Electromagnetic Theory
Office of Naval Research
800 N. Quincy St., Code 1114
Arlington, Virginia 22217-5000

Dear Dr. Madan:

Enclosed are three copies of the progress report for the research project "Signal Processing in Impulsive Electromagnetic Interference" (Grant Number: N00014-91-J-1334). If there is any additional material or information that you need, please let me know. My address and telephone number are given as follows:

School of Electrical Engineering
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Atlanta, Georgia 30332
Phone : (404) 853-9484

Thank you.

Sincerely yours,

Serena M. Zabin
Assistant Professor

encl.
cc: Administrative Grants Officer,
Office of Naval Research
Director, Naval Research Laboratory
Defense Technical Information Center

PROGRESS REPORT FOR THE

OFFICE OF NAVAL RESEARCH

SUBMITTED TO

Dr. Rabinder N. Madan
Program Manager
Systems and Electromagnetic Theory
Office of Naval Research
800 N. Quincy St., Code 1114
Arlington, Virginia 22217-5000

Signal Processing in Impulsive Electromagnetic Interference

June 30, 1991

Principal Investigator

Serena M. Zabin
S.S.# 339-56-6537
Assistant Professor
Georgia Institute of Technology
School of Electrical Engineering
Atlanta, Georgia 30332-0250
Phone: (404) 853-9484

Title:	Signal Processing in Impulsive Electromagnetic Interference
Principal Investigator:	Serena M. Zabin
Location:	Georgia Institute of Technology School of Electrical Engineering Atlanta, GA 30332
Telephone Number:	(404) 853-9484
Grant Number:	N00014-91-J-1334
R&T Number:	4148128---01
Scientific Officer:	Dr. Rabinder N. Madan

SCIENTIFIC OBJECTIVE

Statistical signal processing functions such as signal detection, estimation, and identification play a key role in the development of effective communications, radar, and sonar systems. For example, advanced statistical methods are emerging as being particularly important in digital communications systems operating in channels corrupted by interference from such phenomena as multiple-access noise, intentional jamming, and impulsive noise sources. Conventional demodulation methods, such as coherent matched filtering, often suffer serious performance degradation when subjected to interference of these types; however, this degradation can frequently be eliminated through the use of more sophisticated signal processing techniques.

A central issue in the design of effective signal processing procedures for systems operating in channels such as those noted above is that of channel identification. Although certain aspects of channel identification have been studied extensively, one area in which there is a pressing need for further research is that of identification of impulsive channels. Communication systems are seldom interfered with by white Gaussian noise alone, yet receiving systems in general use are those which are optimum for white Gaussian noise. The man-made electromagnetic environment, and much of the natural one, is basically "impulsive," i.e., it has a highly structured form characterized by significant probabilities of large interference levels. In addition to the man-made electromagnetic environment, there are many other different, common and widely-used communications and remote-sensing type channels where impulsive noise dominates, e.g., extra-low-frequency (ELF) channels, urban radio networks, underwater acoustic channels, and telephone line channels. This is in contrast to the Gaussian noise processes inherent in transmitting and receiving elements. Since the conventional receivers are effectively linear, the impulsive character of the interference can drastically the performance of conventional systems. Furthermore, since it has been well-established that the performance of communications, radar, and sonar systems can be greatly enhanced if the true statistics of the channel are known and exploited, the problem of identification of impulsive noise channels is important in the development of systems that can approach the performance limits set by such channels.

This research project is concerned with the design and development of new nonlinear algorithms for identification of nongaussian noise processes and for reception of signals corrupted by nongaussian noise. In particular, the overall objectives of this research project are: (i) the development of suitable

channel models for impulsive interference; (ii) the derivation and analysis of new globally optimum nonlinear estimation procedures for the identification of impulsive interference channels, and (iii) application of the developed algorithms in the design of optimum and sub-optimum adaptive receivers for the detection of signals in non-Gaussian noise environments.

RESEARCH SUMMARY

During this reporting period, the focus of our work has been on the problem of obtaining identification procedures for impulsive channels that are both asymptotically optimal and practically efficient. Only in this way can we guarantee that the channel identification procedures will accurately model the channel when intermediate-size samples of channel measurements are used, and that the performance of the identification procedures improves as the number of samples used increases. Our emphasis in this area has been on the development of algorithms for fitting the widely-accepted parametric Class A Middleton model to channel measurements. This model has two basic parameters that can be adjusted to fit a wide variety of impulsive noise phenomena occurring in practice.

Within the context of batch estimation, we have developed a consistent and asymptotically efficient estimator of the Class A parameters that is practically efficient as well [13]. The development of this estimator began with an improved method-of-moments estimator of the parameters based on the extraction of two moments chosen for their sensitivity to the channel parameters. We have shown that this moments estimator is relatively simple to implement and yields unique estimates of the parameters that converge to the true parameters at near-optimal rates. We have also shown, via an extensive simulation study, that the estimator yields good estimates of the parameters for moderate sample sizes but that a significant improvement in performance over the method-of-moments estimator is possible if an asymptotically efficient estimator can be found. By initiating Newton's root-finding method on the likelihood equation with the method-of-moments estimator, such an estimator was obtained. Moreover, via an extensive simulations study, it was seen that the proposed Moment/Likelihood procedure yields excellent estimates of the parameters for moderate sample sizes. In addition to the Moment/Likelihood procedure, we have developed an optimization scheme based on the simplex method that can be shown to converge to a relative maximum of the likelihood function. Preliminary analysis of this scheme indicates that it performs very well for small sample sizes. Current activity on the batch estimation problem includes the development of a nonparametric density estimator of the Class A density based on the kernel estimator, which is ideally suited for mixture densities such as the Class A density. This nonparametric identification procedure will be used in the design of robust receivers for detection of signals in Class A noise. Preliminary analysis of this scheme indicates that it also performs very well for small sample sizes.

During this period, we have also considered the problem of recursive estimation of the Class A parameters. Our primary focus has been on the development of recursive channel estimators that are efficient for small sample sizes. Only in this way can we guarantee that our channel estimator is capable of tracking rapidly-varying nongaussian channels. In particular, a global recursive estimator of the parameters is currently being developed that can overcome the shortcomings of conventional recursive stochastic gradient-type algorithms which make them unsuitable for impulsive channel identification. The primary shortcoming is that the conventional algorithms cannot uniquely identify the Class A parameters due to the existence of multiple roots in the asymptotic likelihood equation. This recursive estimator is based on the use of a nonstandard stochastic approximation procedure wherein the standard Fisher's information matrix, which governs the step size in the recursion, is replaced with a "complete-data" information matrix. This complete-data information matrix not only facilitates the implementation of the recursion but also yields a global procedure through which excellent estimates of the parameters are obtained for small sample sizes.

PUBLICATIONS

Journal Articles

[1] S. M. Zabin, H. V. Poor, "Parameter Estimation for Middleton Class A Interference Processes," *IEEE Transactions on Communications*, vol. COM-37, no. 10, pp. 1042-1051, 1989.

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[8] S. M. Zabin, H. V. Poor, "Recursive Estimation of the Class A Noise Model Parameters," *Proceedings of the 22nd Annual Conference on Information Sciences and Systems*, Princeton University, Princeton, NJ, p. 178, March 1988.

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[13] S. M. Zabin, "Optimum Identification of Impulsive Noise Processes," to be presented at the *1991 IEEE International Symposium on Information Theory,* June 1991.

Technical Reports and Theses

[14] S. M. Zabin, "Parameter Estimation for the Class A Middleton Model," M.S. Thesis, Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign. Also Tech. Rep. No. R-1048, UILU-ENG85-2223, July 1985.

[15] S. M. Zabin, "Identification of Impulsive Interference Channels," Ph.D. Dissertation, Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, July 1989. Also Tech. Rep. UILU-ENG-89-2224, Coordinated Science Laboratory, University of Illinois at Urbana-Champaign.

E-21-674
#2

GEORGIA INSTITUTE OF TECHNOLOGY
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December 27, 1991

Dr. Rabinder N. Madan
Program Manager
Systems and Electromagnetic Theory
Office of Naval Research
800 N. Quincy St., Code 1114
Arlington, Virginia 22217-5000

Dear Dr. Madan:

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PROGRESS REPORT FOR THE

OFFICE OF NAVAL RESEARCH

SUBMITTED TO

Dr. Rabinder N. Madan
Program Manager
Systems and Electromagnetic Theory
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800 N. Quincy St., Code 1114
Arlington, Virginia 22217-5000

Signal Processing in Impulsive Electromagnetic Interference

December 31, 1991

Principal Investigator

Serena M. Zabin
S.S.# 339-56-6537
Assistant Professor
Georgia Institute of Technology
School of Electrical Engineering
Atlanta, Georgia 30332-0250
Phone: (404) 853-9484

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Telephone Number:	(404) 853-9484
Grant Number:	N00014-91-J-1334
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SCIENTIFIC OBJECTIVE

Statistical signal processing functions such as signal detection, estimation, and identification play a key role in the development of effective communications, radar, and sonar systems. For example, advanced statistical methods are emerging as being particularly important in digital communications systems operating in channels corrupted by interference from such phenomena as multiple-access noise, intentional jamming, and impulsive noise sources. Conventional demodulation methods, such as coherent matched filtering, often suffer serious performance degradation when subjected to interference of these types; however, this degradation can frequently be eliminated through the use of more sophisticated signal processing techniques.

A central issue in the design of effective signal processing procedures for systems operating in channels such as those noted above is that of channel identification. Although certain aspects of channel identification have been studied extensively, one area in which there is a pressing need for further research is that of identification of impulsive channels. Communication systems are seldom interfered with by white Gaussian noise alone, yet receiving systems in general use are those which are optimum for white Gaussian noise. The man-made electromagnetic environment, and much of the natural one, is basically "impulsive," i.e., it has a highly structured form characterized by significant probabilities of large interference levels. In addition to the man-made electromagnetic environment, there are many other different, common and widely-used communications and remote-sensing type channels where impulsive noise dominates, e.g., extra-low-frequency (ELF) channels, urban radio networks, underwater acoustic channels, and telephone line channels. This is in contrast to the Gaussian noise processes inherent in transmitting and receiving elements. Since the conventional receivers are effectively linear, the impulsive character of the interference can drastically the performance of conventional systems. Furthermore, since it has been well-established that the performance of communications, radar, and sonar systems can be greatly enhanced if the true statistics of the channel are known and exploited, the problem of identification of impulsive noise channels is important in the development of systems that can approach the performance limits set by such channels.

This research project is concerned with the design and development of new nonlinear algorithms for identification of nongaussian noise processes and for reception of signals corrupted by nongaussian noise. In particular, the overall objectives of this research project are: (i) the development of suitable

channel models for impulsive interference; (ii) the derivation and analysis of new globally optimum nonlinear estimation procedures for the identification of impulsive interference channels, and (iii) application of the developed algorithms in the design of optimum and sub-optimum adaptive receivers for the detection of signals in non-Gaussian noise environments.

RESEARCH SUMMARY

During this reporting period, the focus of our work has been on the problem of obtaining optimum and efficient identification and detection procedures for impulsive channels. Of particular interest is the Middleton Class A noise model, which is a widely-accepted statistical-physical model for impulsive interference superimposed on a Gaussian background. The model has two basic parameters that can be adjusted to fit a wide variety of impulsive noise phenomena occurring in practice.

We have considered the problem of basic batch estimation of the Class A parameters. In particular, we have developed a consistent and asymptotically efficient estimator of the Class A parameters that is practically efficient as well [14],[15]. The development of this estimator began with an improved method-of-moments estimator of the parameters based on the extraction of two moments chosen for their sensitivity to the channel parameters. We have shown that this moments estimator is relatively simple to implement and yields unique estimates of the parameters that converge to the true parameters at near-optimal rates. We have also shown, via an extensive simulation study, that the estimator yields good estimates of the parameters for moderate sample sizes but that a significant improvement in performance over the method-of-moments estimator is possible if an asymptotically efficient estimator can be found. The search for such an estimator began with a search for a method which identifies the consistent, and hence, asymptotically efficient sequence of roots to the likelihood equation. One method that has the potential of providing such an estimator is maximum likelihood. We have shown in this study that the maximum likelihood estimate (MLE) is consistent for the Class estimation problem, despite the existence of multiple roots in the asymptotic likelihood equation. However, the existence of these multiple roots makes the MLE very difficult to implement. Fortunately, the consistent sequence of roots can be located using an alternative method. This method consists of initiating Newton's root-finding method on the likelihood equation with the method-of-moments estimator and, in so doing, both the consistency of the moments estimator and the efficiency of likelihood-based estimation are retained. We have shown that this Moment/Likelihood procedure does indeed yield consistent and asymptotically efficient estimates of the parameters. Moreover, via an extensive simulation study, it was seen that the proposed Moment/Likelihood procedure yields excellent estimates of the parameters for moderate sample sizes. In addition, we have developed an optimization scheme based on the simplex method that can be shown to converge to a relative maximum of the likelihood function. An extensive simulation study of this scheme indicates that it performs very well for small sample sizes.

The problem of recursive estimation of the Class A parameters was also investigated. Our primary objective in this phase of the study was the development of recursive channel estimators that are efficient for small sample sizes. Only in this way can we guarantee that our channel estimator is capable of tracking rapidly-varying nongaussian channels. In particular, we have developed a global recursive estimator of the parameters that can overcome the shortcomings of conventional recursive stochastic gradient-type algorithms which make them unsuitable for impulsive channel identification. The primary shortcoming is that the conventional algorithms cannot uniquely identify the Class A parameters due to the existence of multiple roots in the asymptotic likelihood equation. This recursive estimator is based on the use of a nonstandard stochastic approximation procedure wherein the standard Fisher's information matrix, which governs the step size in the recursion, is replaced with a "complete-data" information matrix. Two initiating estimators for this complete-data stochastic approximation procedure were developed. The first is a batch estimator which extracts estimates of the parameters directly from a histogram of the Class A envelope data. The second is a method-of-moments estimator applied to a nontraditional set of observations, referred to as "complete-data." At each iteration of this initiating recursive estimator, complete data are generated from the traditional, or incomplete, observations using the estimate of the parameters obtained at the previous iteration. A fixed parameter vector in the parameter space initiates the process. By equating sample moments of the complete data to the true moments, estimates of the parameters are then obtained. Both initiating estimators were found to yield estimates which lie in the region of convergence of the stochastic approximation procedure. Moreover, via an extensive simulation study, it was seen that the proposed stochastic-approximation-based estimators yielded global recursive procedures through which excellent estimates of the parameters were obtained for small sample sizes.

During this period, we have also developed efficient detection algorithms for a wide range of impulsive noise models, including the Class A, Johnson, and Laplacian models. The design of these detection schemes was based on the use of nonparametric density estimates in the optimum detection strategy. In particular, we have considered nonparametric density estimates based on the kernel estimator, which is well-suited for the heavy-tailed distributions considered in this study. Various modifications to the basic form of this estimator were made in order to improve its performance for small samples sizes. These modifications include: (i) a nonsymmetric kernel estimator for estimating envelope densities; and (ii) a heuristically-motivated variable-kernel estimator based on a generalization of the automatic and nearest-neighbor kernel estimates. These density estimates were then used in the design of efficient adaptive receivers for detection of signals in the aforementioned noise environments. In particular, the adaptive receiver for the small-signal detection problem was constructed by estimating the optimum small-signal nonlinearity using the nonparametric density estimates. The efficiency of the nonlinear detectors formed with the kernel estimator were then compared to the locally-optimum detector based on the actual interference density. Via an extensive small-sample-size performance analysis, it was seen that the proposed detection schemes yielded near-optimum performance for the wide class of impulsive noise densities considered in this study.

PUBLICATIONS

Journal Articles

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[17] S. M. Zabin, "Identification of Impulsive Interference Channels," Ph.D. Dissertation, Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, July 1989. Also Tech. Rep. UILU-ENG-89-2224, Coordinated Science Laboratory, University of Illinois at Urbana-Champaign.

E21-674
#3

GEORGIA INSTITUTE OF TECHNOLOGY
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June 25, 1992

Dr. Rabinder N. Madan
Program Manager
Systems and Electromagnetic Theory
Office of Naval Research
800 N. Quincy St., Code 1114
Arlington, Virginia 22217-5000

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Signal Processing in Impulsive Electromagnetic Interference

June 30, 1992

Principal Investigator

Serena M. Zabin
S.S.# 339-56-6537
Assistant Professor
Georgia Institute of Technology
School of Electrical Engineering
Atlanta, Georgia 30332-0250
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Grant Number:	N00014-91-J-1334
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We have considered the problem of basic batch estimation of the Class A parameters [15]-[17]. In particular, we have developed a consistent and asymptotically efficient estimator of the Class A parameters that is practically efficient as well. The development of this estimator began with an improved method-of-moments estimator of the parameters based on the extraction of two moments chosen for their sensitivity to the channel parameters. We have shown that this moments estimator is relatively simple to implement and yields unique estimates of the parameters that converge to the true parameters at near-optimal rates. We have also shown, via an extensive simulation study, that the estimator yields good estimates of the parameters for moderate sample sizes but that a significant improvement in performance over the method-of-moments estimator is possible if an asymptotically efficient estimator can be found. The search for such an estimator began with a search for a method which identifies the consistent, and hence, asymptotically efficient sequence of roots to the likelihood equation. One method that has the potential of providing such an estimator is maximum likelihood. We have shown in this study that the maximum likelihood estimate (MLE) is consistent for the Class estimation problem, despite the existence of multiple roots in the asymptotic likelihood equation. However, the existence of these multiple roots makes the MLE very difficult to implement. Fortunately, the consistent sequence of roots can be located using an alternative method. This method consists of initiating Newton's root-finding method on the likelihood equation with the method-of-moments estimator and, in so doing, both the consistency of the moments estimator and the efficiency of likelihood-based estimation are retained. We have shown that this Moment/Likelihood procedure does indeed yield consistent and asymptotically efficient estimates of the parameters. Moreover, via an extensive simulation study, it was seen that the proposed Moment/Likelihood procedure yields excellent estimates of the parameters for moderate sample sizes. In addition, we have developed an optimization scheme based on the simplex method that can be shown to converge to a relative maximum of the likelihood function. An extensive simulation study of this scheme indicates that it performs very well for small sample sizes.

The problem of recursive estimation of the Class A parameters was also investigated. Our primary objective in this phase of the study was the development of recursive channel estimators that are efficient for small sample sizes. Only in this way can we guarantee that our channel estimator is capable of tracking rapidly-varying nongaussian channels. In particular, we have developed a global recursive estimator of the parameters that can overcome the shortcomings of conventional recursive stochastic gradient-type algorithms which make them unsuitable for impulsive channel identification. The primary shortcoming is that the conventional algorithms cannot uniquely identify the Class A parameters due to the existence of multiple roots in the asymptotic likelihood equation. This recursive estimator is based on the use of a nonstandard stochastic approximation procedure wherein the standard Fisher's information matrix, which governs the step size in the recursion, is replaced with a "complete-data" information matrix. Two initiating estimators for this complete-data stochastic approximation procedure were developed. The first is a batch estimator which extracts estimates of the parameters directly from a histogram of the Class A envelope data. The second is a method-of-moments estimator applied to a nontraditional set of observations, referred to as "complete-data." At each iteration of this initiating recursive estimator, complete data are generated from the traditional, or incomplete, observations using the estimate of the parameters obtained at the previous iteration. A fixed parameter vector in the parameter space initiates the process. By equating sample moments of the complete data to the true moments, estimates of the parameters are then obtained. Both initiating estimators were found to yield estimates which lie in the region of convergence of the stochastic approximation procedure. Moreover, via an extensive simulation study, it was seen that the proposed stochastic-approximation-based estimators yielded global recursive procedures through which excellent estimates of the parameters were obtained for small sample sizes.

During this period, we have also developed efficient detection algorithms for a wide range of impulsive noise models, including the Class A, Johnson, and Laplacian models. The design of these detection schemes was based on the use of nonparametric density estimates in the optimum detection strategy. In particular, we have considered nonparametric density estimates based on the kernel estimator, which is well-suited for the heavy-tailed distributions considered in this study. Various modifications to the basic form of this estimator were made in order to improve its performance for small samples sizes. These modifications include: (i) a nonsymmetric kernel estimator for estimating envelope densities; and (ii) a heuristically-motivated variable-kernel estimator based on a generalization of the automatic and nearest-neighbor kernel estimates. These density estimates were then used in the design of efficient adaptive receivers for detection of signals in the aforementioned noise environments. In particular, the adaptive receiver for the small-signal detection problem was constructed by estimating the optimum small-signal nonlinearity using the nonparametric density estimates. The efficiency of the nonlinear detectors formed with the kernel estimator were then compared to the locally-optimum detector based on the actual interference density. Via an extensive small-sample-size performance analysis, it was seen that the proposed detection schemes yielded near-optimum performance for the wide class of impulsive noise densities considered in this study.

<u>PUBLICATIONS</u>

Journal Articles

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[5] S. M. Zabin, D. S. Furbeck, "Maximum Likelihood Estimation of Nongaussian Mixtures," in preparation for submission to *IEEE Transactions on Communications.*

[6] S. M. Zabin, G. F. Wright, "New Techniques for Estimation of Envelope Densities," in preparation for submission to *IEEE Transactions on Information Theory.*

[7] S. M. Zabin, "Optimal Identification of Impulsive Interference Processes," in preparation for submission to *IEEE Transactions on Information Theory.*

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Technical Reports and Theses

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December 29, 1992

Dr. Rabinder N. Madan
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Arlington, Virginia 22217-5000

Dear Dr. Madan:

Enclosed are three copies of the progress report for the research project "Signal Processing in Impulsive Electromagnetic Interference" (Grant Number: N00014-91-J-1334). If there is any additional material or information that you need, please let me know. Thank you.

Sincerely yours,

Serena M. Zabin
Assistant Professor

encl.
cc: Administrative Grants Officer,
Office of Naval Research
Director, Naval Research Laboratory
Defense Technical Information Center

PROGRESS REPORT FOR THE

OFFICE OF NAVAL RESEARCH

SUBMITTED TO

Dr. Rabinder N. Madan
Program Manager
Systems and Electromagnetic Theory
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Arlington, Virginia 22217-5000

Signal Processing in Impulsive Electromagnetic Interference

December 31, 1992

Principal Investigator

Serena M. Zabin
S.S.# 339-56-6537
Assistant Professor
Georgia Institute of Technology
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Title: Signal Processing in Impulsive Electromagnetic Interference

Principal Investigator: Serena M. Zabin

Location: Georgia Institute of Technology
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Telephone Number: (404) 853-9484

Grant Number: N00014-91-J-1334

R&T Number: 4148128---01

Scientific Officer: Dr. Rabinder N. Madan

SCIENTIFIC OBJECTIVE

Statistical signal processing functions such as signal detection, estimation, and identification play a key role in the development of effective communications, radar, and sonar systems. For example, advanced statistical methods are emerging as being particularly important in digital communications systems operating in channels corrupted by interference from such phenomena as multiple-access noise, intentional jamming, and impulsive noise sources. Conventional demodulation methods, such as coherent matched filtering, often suffer serious performance degradation when subjected to interference of these types; however, this degradation can frequently be eliminated through the use of more sophisticated signal processing techniques.

A central issue in the design of effective signal processing procedures for systems operating in channels such as those noted above is that of channel identification. Although certain aspects of channel identification have been studied extensively, one area in which there is a pressing need for further research is that of identification of impulsive channels. Communication systems are seldom interfered with by white Gaussian noise alone, yet receiving systems in general use are those which are optimum for white Gaussian noise. The man-made electromagnetic environment, and much of the natural one, is basically "impulsive," i.e., it has a highly structured form characterized by significant probabilities of large interference levels. In addition to the man-made electromagnetic environment, there are many other different, common and widely-used communications and remote-sensing type channels where impulsive noise dominates, e.g., extra-low-frequency (ELF) channels, urban radio networks, underwater acoustic channels, and telephone line channels. This is in contrast to the Gaussian noise processes inherent in transmitting and receiving elements. Since the conventional receivers are effectively linear, the impulsive character of the interference can drastically the performance of conventional systems. Furthermore, since it has been well-established that the performance of communications, radar, and sonar systems can be greatly enhanced if the true statistics of the channel are known and exploited, the problem of identification of impulsive noise channels is important in the development of systems that can approach the performance limits set by such channels.

This research project is concerned with the design and development of new nonlinear algorithms for identification of nongaussian noise processes and for reception of signals corrupted by nongaussian noise. In particular, the overall objectives of this research project are: (i) the development of suitable

channel models for impulsive interference; (ii) the derivation and analysis of new globally optimum nonlinear estimation procedures for the identification of impulsive interference channels, and (iii) application of the developed algorithms in the design of optimum and sub-optimum adaptive receivers for the detection of signals in non-Gaussian noise environments.

RESEARCH SUMMARY

During this reporting period, the focus of our work has been on the problem of obtaining optimum and efficient identification and detection procedures for impulsive channels. Of particular interest is the Middleton Class A noise model, which is a widely-accepted statistical-physical model for impulsive interference superimposed on a Gaussian background. The model has two basic parameters that can be adjusted to fit a wide variety of impulsive noise phenomena occurring in practice.

We have considered the problem of basic batch estimation of the Class A parameters. In particular, we have developed a consistent and asymptotically efficient estimator of the Class A parameters that is practically efficient as well [16],[17]. The development of this estimator began with an improved method-of-moments estimator of the parameters based on the extraction of two moments chosen for their sensitivity to the channel parameters. We have shown that this moments estimator is relatively simple to implement and yields unique estimates of the parameters that converge to the true parameters at near-optimal rates. We have also shown, via an extensive simulation study, that the estimator yields good estimates of the parameters for moderate sample sizes but that a significant improvement in performance over the method-of-moments estimator is possible if an asymptotically efficient estimator can be found. The search for such an estimator began with a search for a method which identifies the consistent, and hence, asymptotically efficient sequence of roots to the likelihood equation. One method that has the potential of providing such an estimator is maximum likelihood. We have shown in this study that the maximum likelihood estimate (MLE) is consistent for the Class estimation problem, despite the existence of multiple roots in the asymptotic likelihood equation [6]. However, the existence of these multiple roots makes the MLE very difficult to implement. Fortunately, the consistent sequence of roots can be located using an alternative method. This method consists of initiating Newton's root-finding method on the likelihood equation with the method-of-moments estimator and, in so doing, both the consistency of the moments estimator and the efficiency of likelihood-based estimation are retained. We have shown that this Moment/Likelihood procedure does indeed yield consistent and asymptotically efficient estimates of the parameters. Moreover, via an extensive simulation study, it was seen that the proposed Moment/Likelihood procedure yields excellent estimates of the parameters for moderate sample sizes. In addition, we have developed an optimization scheme based on the simplex method that can be shown to converge to a relative maximum of the likelihood function. An extensive simulation study of this scheme indicates that it performs very well for small sample sizes.

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SUBMITTED TO

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Signal Processing in Impulsive Electromagnetic Interference

June 30, 1993

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The problem of recursive estimation of the Class A parameters was also investigated [7]. Our primary objective in this phase of the study was the development of recursive channel estimators that are efficient for small sample sizes. Only in this way can we guarantee that our channel estimator is capable of tracking rapidly-varying nongaussian channels. In particular, we have developed a global recursive estimator of the parameters that can overcome the shortcomings of conventional recursive stochastic gradient-type algorithms which make them unsuitable for impulsive channel identification. The primary shortcoming is that the conventional algorithms cannot uniquely identify the Class A parameters due to the existence of multiple roots in the asymptotic likelihood equation. This recursive estimator is based on the use of a nonstandard stochastic approximation procedure wherein the standard Fisher's information matrix, which governs the step size in the recursion, is replaced with a "complete-data" information matrix. Two initiating estimators for this complete-data stochastic approximation procedure were developed. The first is a batch estimator which extracts estimates of the parameters directly from a histogram of the Class A envelope data. The second is a method-of-moments estimator applied to a nontraditional set of observations, referred to as "complete-data." At each iteration of this initiating recursive estimator, complete data are generated from the traditional, or incomplete, observations using the estimate of the parameters obtained at the previous iteration. A fixed parameter vector in the parameter space initiates the process. By equating sample moments of the complete data to the true moments, estimates of the parameters are then obtained. Both initiating estimators were found to yield estimates which lie in the region of convergence of the stochastic approximation procedure. Moreover, via an extensive simulation study, it was seen that the proposed stochastic-approximation-based estimators yielded global recursive procedures through which excellent estimates of the parameters were obtained for small sample sizes.

During this period, we have also developed and analyzed the performance of several nonparametric density estimators and detectors for impulsive noise channels [4],[5]. These nonparametric density estimators exploit the known properties of the given noise environments and, in so doing, yield estimates that closely approximate the true densities for small sample sizes. Two estimators have been proposed: the first is particular to envelope densities, while the second is designed for symmetric instantaneous amplitude densities. The standard automatic kernel and variable kernel estimators provided the basis for the construction of these two estimators. By incorporating the two-component structure of the impulsive noise densities to be estimated into the framework of these estimators and choosing the variables of the estimators appropriately, tremendous improvements in performance over the basic kernel estimators were achieved. In addition, a method for evaluating the L_1-performance of an "optimum" parametric-based density estimator was derived. Upon using this method, it was seen that the performance of the proposed nonparametric density estimators was comparable to that of their optimum counterparts for small values of the sample size for the wide variety of impulsive noise densities considered in this study. These nonparametric density estimators were then used in the development of various detection strategies. In particular, two likelihood ratio tests were formulated using these density estimators, one based on the classical robust test, the other on the L_1-error-based detector. Via an extensive simulation study, it was seen that the performance of these schemes was very near that of the optimum likelihood ratio test for small values of the sample size. The proposed nonparametric density estimators were then used in the development of a weak-signal detector that approximates the locally optimum nonlinearity. By using the basic features of the robust and L_1-error-based tests, a "precensoring" method was developed for this detector which suppresses the effects of errors in the density estimates. Via an extensive small-sample size performance analysis, the performance of the resulting detector was found to be very near that of the optimum nonlinearity for the wide class of densities considered in this study. Furthermore, for a variety of impulsive noise densities this detection scheme was shown to outperform several classical nonparametric detectors.

A nonparametric density estimator for positive random variables was also developed and analyzed [8]. This kernel-based estimator makes use of a basic feature of positive random variables in its design, namely that a positive random variable can be represented as the norm of a random vector having arbitrary direction. Among other applications, this approach is well-suited for estimating densities of the envelope of electronic and acoustic waveforms (e.g., the norm of the in-phase and quadrature components of signals). Depending on the dimension of the normed vector space that is employed, this estimator also assumes different forms, each form being applicable to a different class of densities. The proposed estimator was analyzed extensively. First, the estimator was shown to possess some of the usual desirable properties of nonparametric estimators, such as pointwise and L_1-consistency. Then, an upper bound on the expected value of the L_1 error was derived and, using a minimax strategy, the optimal kernel and smoothing factor for the estimator were determined. In addition, the appropriate forms of the estimator for the different classes of densities were specified. Finally, the asymptotic performance of the proposed estimator and the standard kernel estimator (restricted to the nonnegative real axis) were compared using the derived upper bound on the expected value of the L_1 error. Via this comparison, the proposed scheme was seen to outperform the standard estimator for a wide variety of densities.

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[1] S. M. Zabin, H. V. Poor, "Parameter Estimation for Middleton Class A Interference Processes," *IEEE Transactions on Communications,* vol. COM-37, no. 10, pp. 1042-1051, 1989.

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FINAL REPORT FOR THE

OFFICE OF NAVAL RESEARCH

SUBMITTED TO

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Signal Processing in Impulsive Electromagnetic Interference

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SCIENTIFIC OBJECTIVE

Statistical signal processing functions such as signal detection and estimation play a key role in the development of effective communications, radar, and sonar systems. For example, advanced statistical methods are emerging as being particularly important in digital communications systems operating in channels corrupted by impulsive interference. Conventional processing methods often suffer serious performance degradation when subjected to interference of this types; however, this degradation can frequently be eliminated through the use of more sophisticated techniques.

A central issue in the design of processing procedures for systems operating in channels such as those noted above is that of channel identification. Although certain aspects of channel identification have been studied extensively, one area in which there is a pressing need for further research is that of identification of impulsive channels. Thus, this research project is concerned with the development of new algorithms for identification of nongaussian noise processes and for reception of signals corrupted by nongaussian noise. In particular, the overall objectives of this research project are: (i) the development of suitable channel models for impulsive interference; (ii) the derivation and analysis of new global estimation procedures for the identification of impulsive interference channels, and (iii) application of the developed algorithms in the design of receivers for the detection of signals in non-Gaussian noise environments.

RESEARCH SUMMARY

The problem of obtaining optimum esimation and detection procedures for impulsive channels has been examined extensively in this study. Of particular interest was the Middleton Class A noise model, which is a widely-accepted statistical-physical model for impulsive interference superimposed on a Gaussian background. The model has two basic parameters that can be adjusted to fit a wide variety of impulsive noise phenomena occurring in practice.

The problem of basic batch estimation of the Class A parameters was considered first. In particular, we have developed a consistent and asymptotically efficient estimator of the Class A parameters that is practically efficient as well [17],[18]. The problem of batch and recursive estimation of the Class A parameters was also investigated in [6],[7], wherein we have developed estimators of the parameters that can overcome the shortcomings of conventional gradient-type algorithms which make them unsuitable for impulsive channel identification.

We have also developed and analyzed the performance of several nonparametric density estimators and detectors for impulsive noise channels [4],[5]. These nonparametric density estimators exploit the known properties of the given noise environments and, in so doing, yield estimates that closely approximate the true densities for small sample sizes. Two estimators have been proposed: the first is particular to envelope densities, while the second is designed for symmetric instantaneous amplitude densities. The standard automatic kernel and variable kernel estimators provided the basis for the construction of these two estimators. By incorporating the two-component structure of the impulsive noise densities to be estimated into the framework of these estimators and choosing the variables of the estimators appropriately, tremendous improvements in performance over the basic kernel estimators were achieved. In addition, a method for evaluating the L_1-performance of an "optimum" parametric-based density estimator was derived. Upon using this method, it was seen that the performance of the proposed nonparametric density estimators was comparable to that of their optimum counterparts for small values of the sample size for the wide variety of impulsive noise densities considered in this study. These nonparametric density estimators were then used in the development of various detection strategies. In particular, two likelihood ratio tests were formulated using these density estimators, one based on the classical robust test, the other on the L_1-error-based detector. Via an extensive simulation study, it was seen that the performance of these schemes was very near that of the optimum likelihood ratio test for small values of the sample size. The proposed nonparametric density estimators were then used in the development of a weak-signal detector that approximates the locally optimum nonlinearity. By using the basic features of the robust and L_1-error-based tests, a "precensoring" method was developed for this detector which suppresses the effects of errors in the density estimates. Via an extensive small-sample size performance analysis, the performance of the resulting detector was found to be very near that of the optimum nonlinearity for the wide class of densities considered in this study. Furthermore, for a variety of impulsive noise densities this detection scheme was shown to outperform several classical nonparametric detectors.

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